STRATEGIES FOR ADAPTIVE RADIATION THERAPY: ROBUST DEFORMABLE IMAGE REGISTRATION USING HIGH PERFORMANCE COMPUTING AND ITS CLINICAL APPLICATIONS

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Abstract

Image guided radiation therapy (IGRT) requires developing advanced methods for target localization. Once target motion is identified, the patient specific treatment margin can be incorporated into the treatment planning, accurately delivering the radiation dose to the target and minimizing the dose to the normal tissues. Deformable image registration (DIR) has become an indispensable tool to analyze target motion and measure physiological change by temporal imaging or time series volumetric imaging, such as four-dimensional computed tomography (4DCT). Current DIR algorithms suffer from inverse inconsistency, where the deformation mapping is not unique after switching the order of the images. Moreover, long computation time of current DIR implementation limits its clinical application to offline analysis.

This dissertation makes three major contributions: First, an inverse consistent constraint (ICC) is proposed to constrain the uniqueness of the correspondence between image pairs. The proposed ICC has the advantage of 1) improving registration accuracy and robustness, 2) not requiring explicitly computing the inverse of the deformation field, and 3) reducing the inverse consistency error (ICE). Moreover, a variational registration model, based on the maximum likelihood estimation, is proposed to accelerate the algorithm convergence and allow for inexact image pixel matching within an optimized variation for noisy image pairs. The algorithm evaluation was carried out using a simulated phantom, a four-dimensional single photon emission computed tomography myocardium phantom, and clinical 4DCT images. After applying ICC, the ICE was reduced by up to 99% and the phantom error was reduced by up to 32%. For noisy image pairs, the likelihood based inverse consistent DIR algorithm achieved fast convergence and attained a phantom error reduction of 56%, compared to the classic fast diffusion registration algorithms. Second, an auto re-contouring framework is developed for automatically propagate the planning contours in the planning image dataset to a new image dataset. It consists of DIR, surface reconstruction, and post processing. Visual estimation was applied to evaluate the re-contouring performance. The auto re-contouring framework is also applied to automatic generating internal target volume (ITV) and its probability density function by combing auto-contoured gross tumor volume of

phase CTs. Third, a proof of concept study was carried out to accelerate the DIR computation using high performance graphics processing unit (GPU). It was demonstrated that the GPU implementation of DIR was able to speed up the computation by up to 60 times, achieved near real-time performance of DIR for clinical images (i.e., 1.8 seconds for image pairs with the size of 256 x 256 x 30 for 100 iterations) and improved the feasibility of applying deformable image registration in routine clinic procedures.